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Jeffrey Muss

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15 Apr 2003

SUBJECT: Authorization for Release of Technical Information, Control Number: **AFRL-PR-ED-VG-2003-090**
Muss, Jeffrey (Sierra Engineering), "5Klbf Unielement TCA for Film Cooling Model "

5740

NASA Fluids Workshop (U.S. Citizens Only)
(Biremingham, AL, 22-24 Apr 2003) (Deadline: 21 Apr 2003 – RUSH, per PAK)

(Statement A)

5Klbf Unielement TCA for Film Cooling Model Validation

Jeffrey Muss

Sierra Engineering

24 April 2003

Overview

1. Problem Statement & Applicability
2. Hardware Characteristics
3. Test Program
4. Data Reduction Approach
5. Summary

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Problem Statement:

- Very limited test data available to validating the potential of liquid RP-1 film cooling at high pressures

Applications:

- Northrop-Grumman's TR107 hydrocarbon engine relies extensively on film cooling for MCC thermal management
- Liquid / gaseous film cooling model refinement applicable for design and analysis of target applications

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5K Test Objectives

- Collect film cooling performance data
  - Hot gas recovery temperature
  - Convective heat transfer coefficient (Hg)
  - Single versus dual film cooling data
  - Wall compatibility / spatial uniformity
  - Operability
- Demonstrate “full size” element
  - Performance
  - Data for “scalability” of elements
    - Currently elements tested at 400 lbf level
    - Chamber pressure 1/2 (<1200 psia)
    - Data with “hot” gO_2

5K Hardware Characteristics

- Operating conditions tied to full-sized TR107
  - Ox-rich staged combustion oxidizer
  - Main element operation characteristics matched
  - Predicted maximum material temperatures bracketed
  - Wall-to-element dimensions matched
  - Chamber characteristic lengths and accelerations matched
  - Passage dimensions matched
- Heavily instrumented for model validation
- Workhorse hardware with some flight-type characteristics

Result is Modular Design

Modular Test Hardware Design

- Main Injector Assembly
- Ablative Hardware
  - Main Injector
  - Igniter Flange
  - Ablative Chamber
- Work Horse Hardware
  - Film Coolant Injection Rings (2)
  - Instrumented Barrel
  - Instrumented Nozzle
- Flight Type Sleeve Hardware
  - Flight Type Sleeve
  - Flight Type Sleeve Backup Chamber

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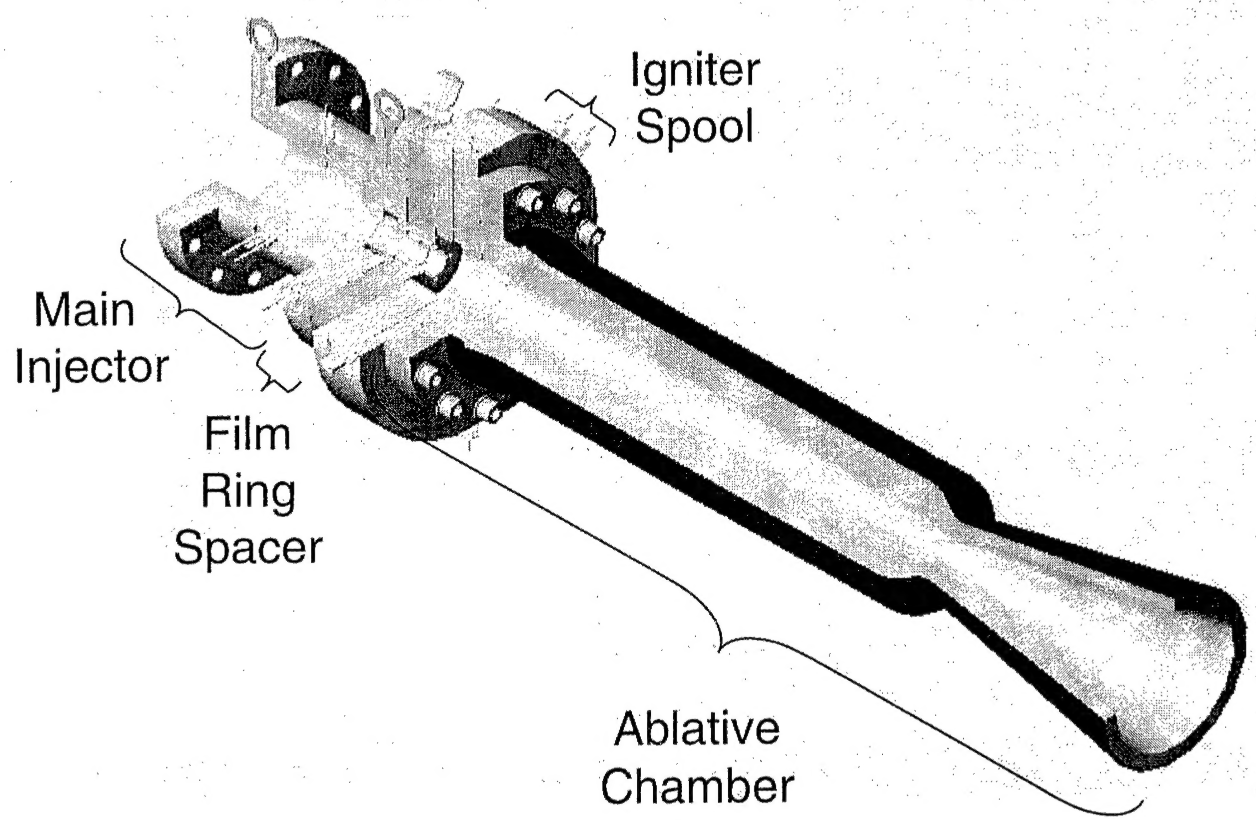
Ablative Chamber Assembly
No Film Cooling

Objectives:
1. Demonstrate ability to run ORPB with TCA downstream
2. Demonstrate ignition of TCA main injector
3. Demonstrate TCA injector element performance



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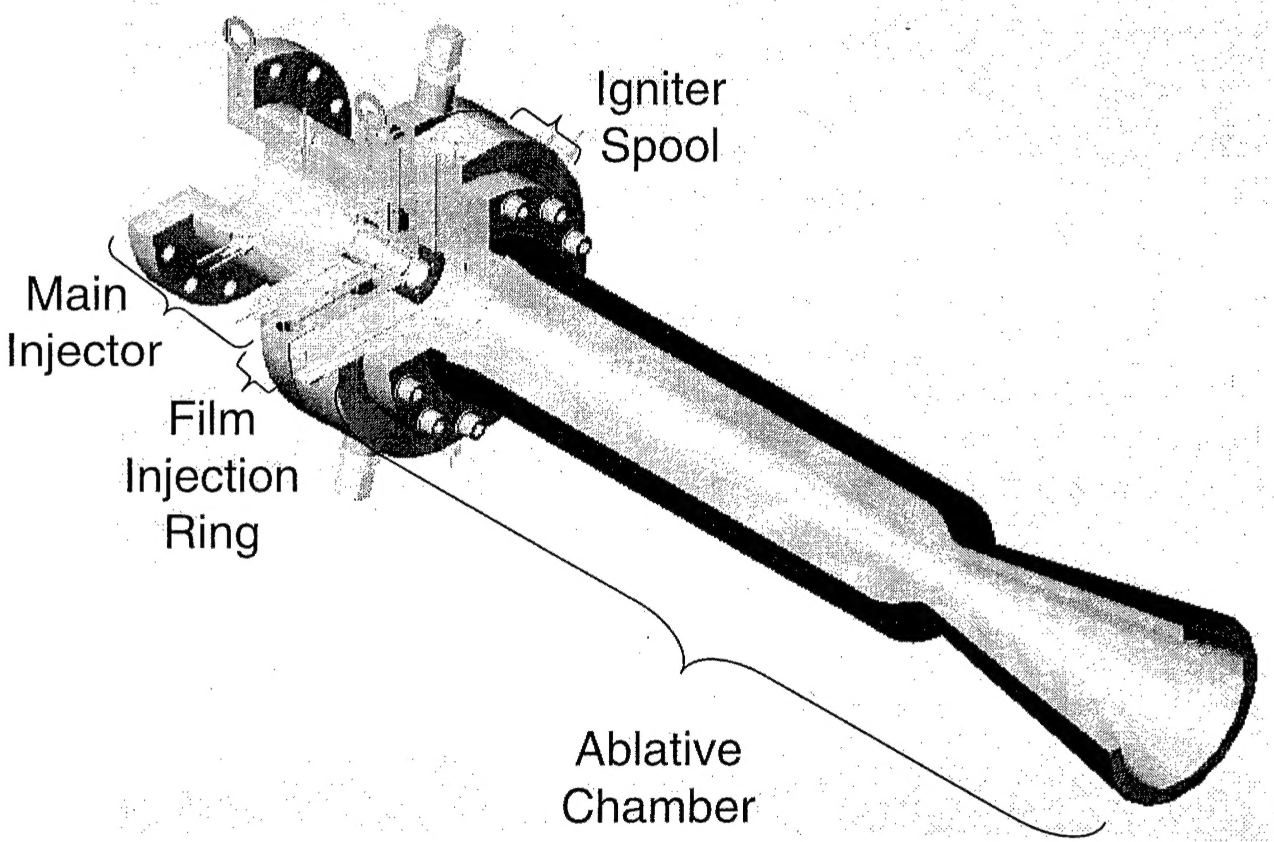
Ablative Chamber Assembly with Fwd FFC Assembly

Objectives:

1. Demonstrate ability to run ORPB with TCA downstream, with film cooling
2. Demonstrate ignition of TCA main injector, with film cooling
3. Demonstrate TCA injector element performance, with film cooling



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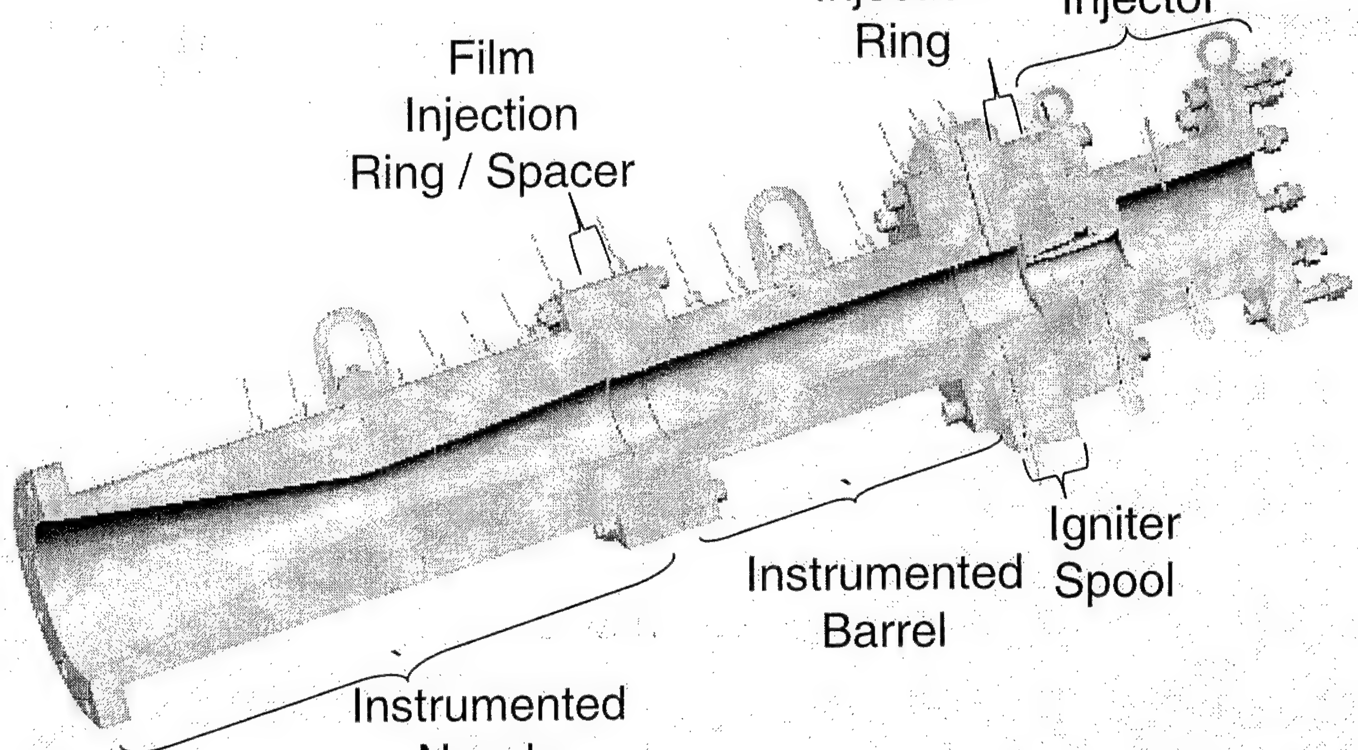
Work Horse Assembly

Objectives:

1. Demonstrate ability to run ORPB with TCA downstream, with dual injection film cooling
2. Demonstrate TCA injector element performance, with dual point film cooling
3. Collect film cooling performance data as a function of film and geometric parameters



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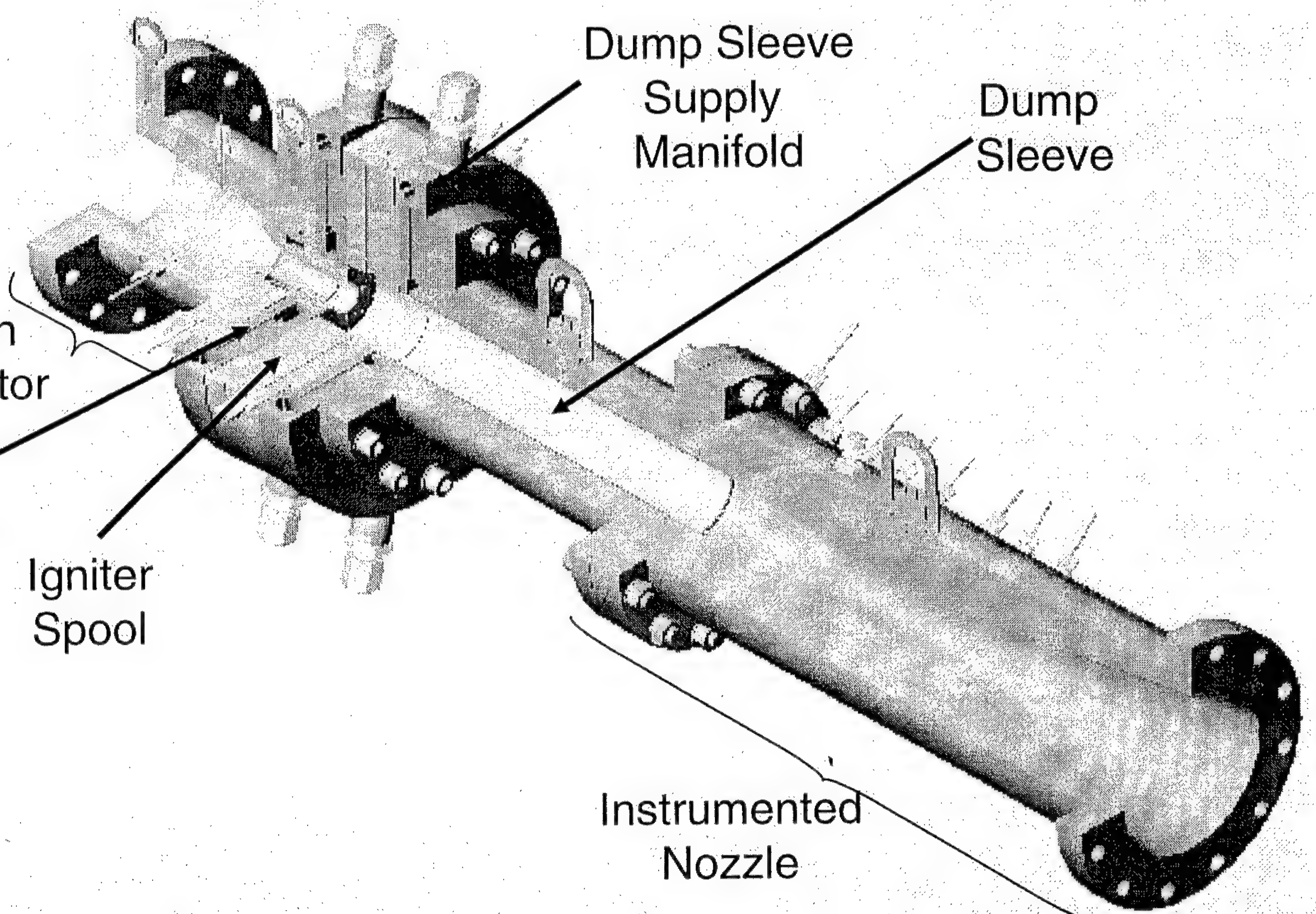
Flight Type Sleeve Testing Assembly

Objectives:

1. Demonstrate “flight” type dump sleeve



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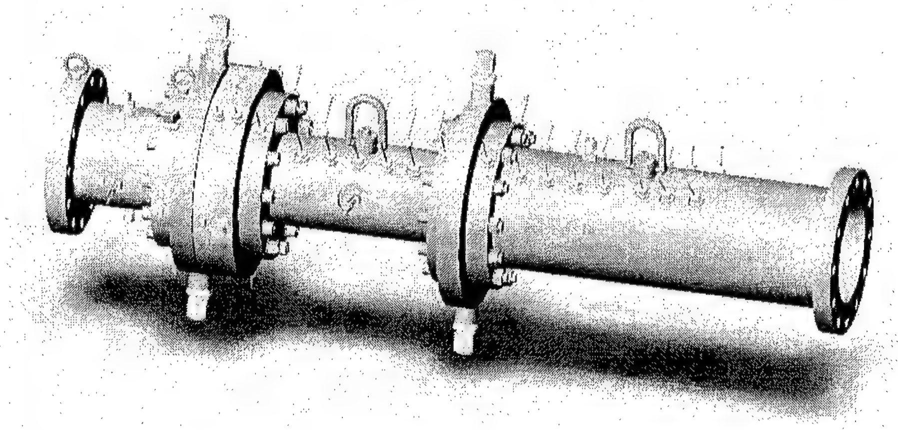
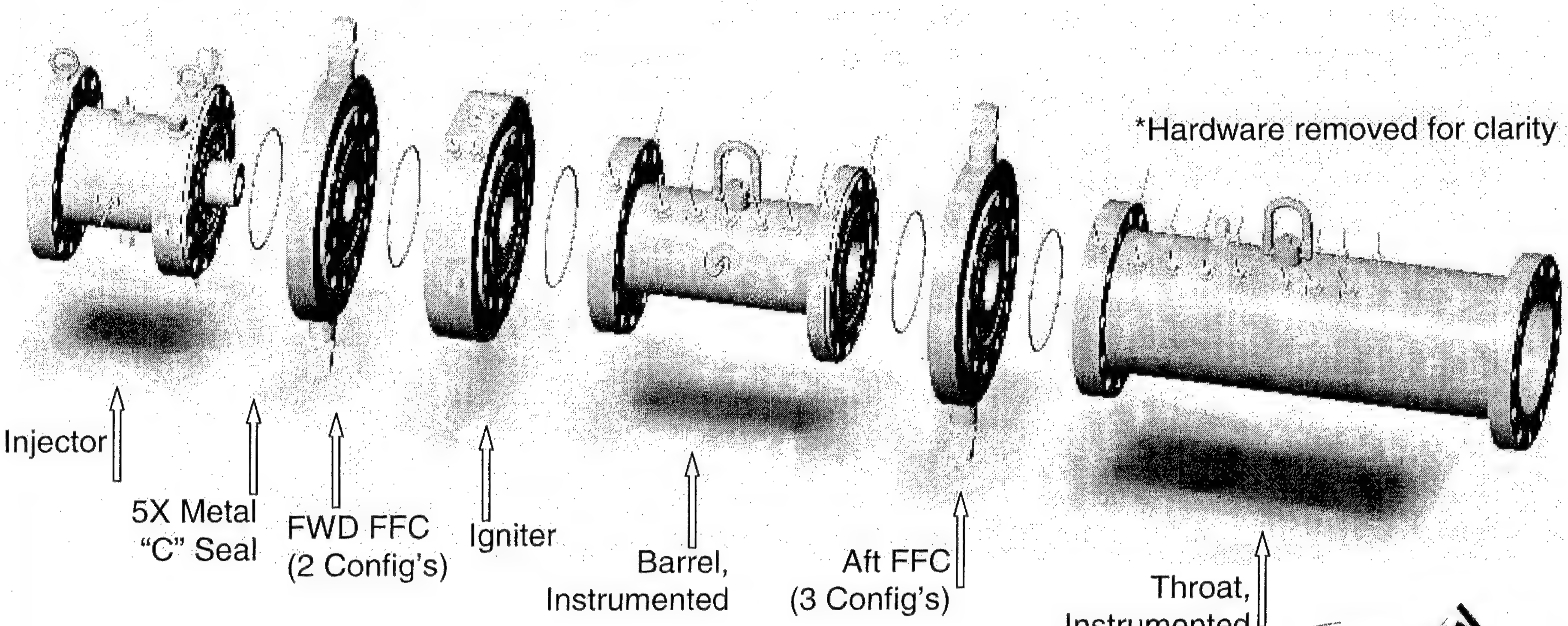
Workhorse Chamber Assembly



- 6 Testable Configurations
  - Allows for parametric study of film cooling
  - Dual Point FFC, Test Matrix (Test Series 7)
  - Single Point FFC (Test Series 8 and 9)

*Hardware removed for clarity



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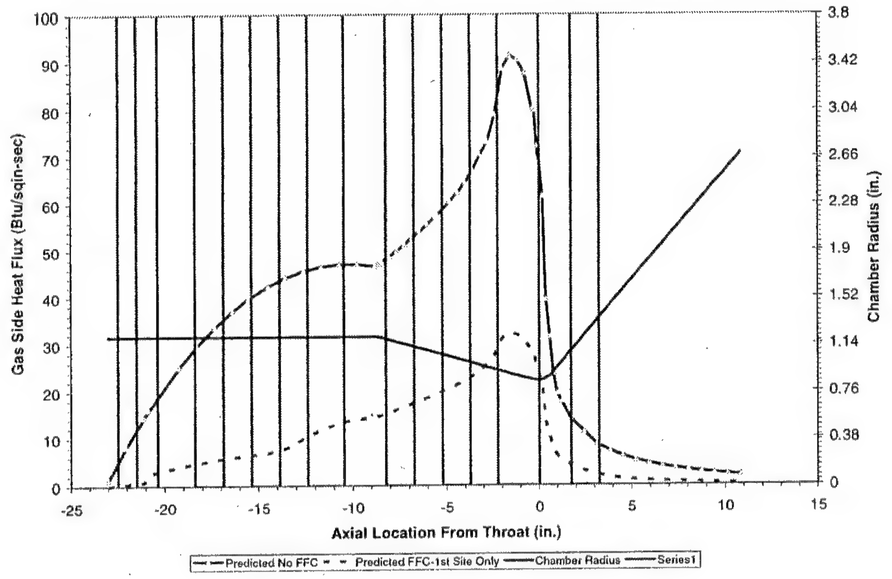
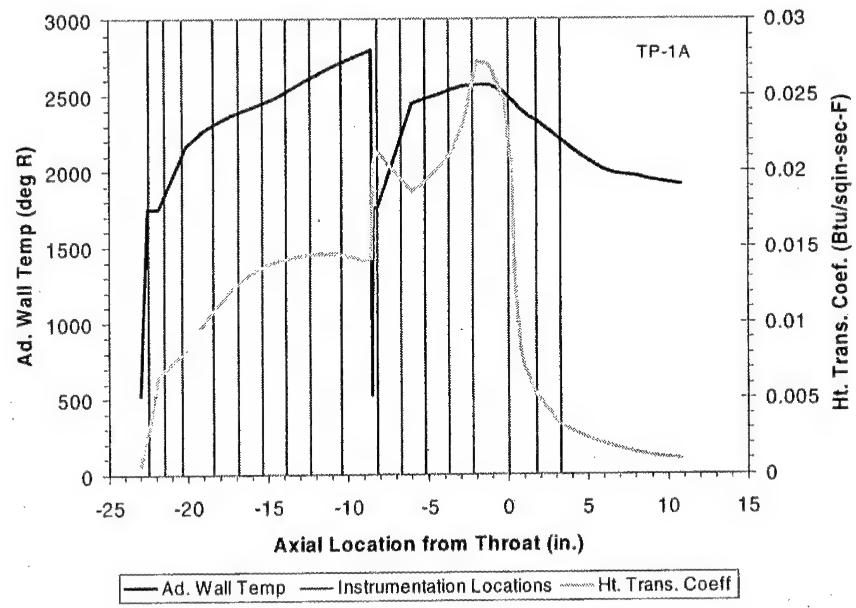
Wall Temperature Measurement Locations Established to Capture Critical Film Cooling Factors





Factors influencing film cooling performance & instrumentation placement:

1. Core gas condition, i.e. un-accelerated, accelerating, diverging nozzle
   - Instrumentation placed to measure these effects
2. Decomposition length of supercritical coolant
   - Predicted decomposition lengths used to select near injection locations
3. Hardware design / cost
   - Flange size / location, bolt access
   - Limited budget for instrumentation

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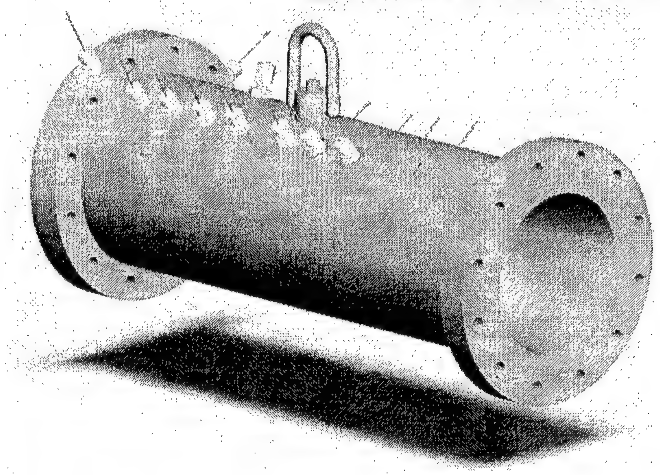
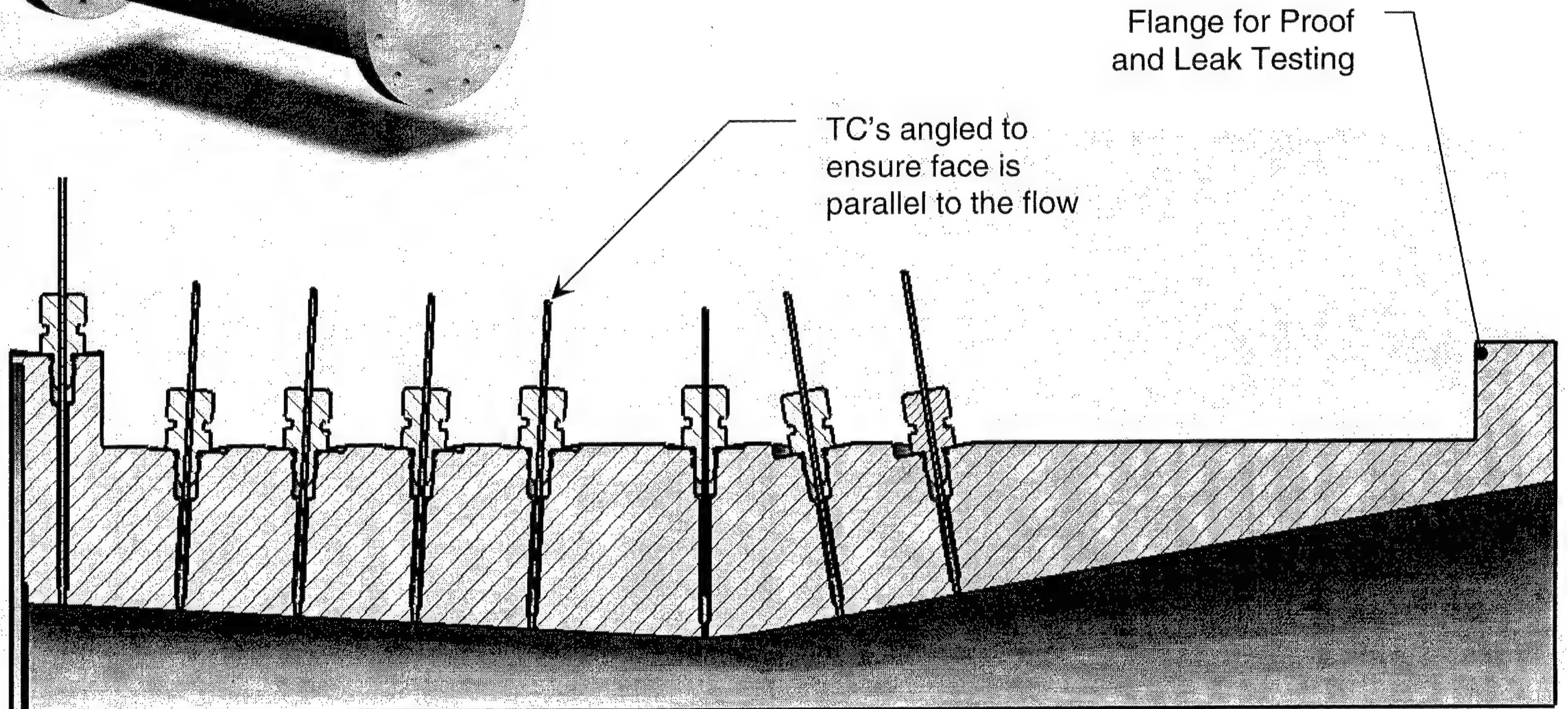
Instrumented Throat Design Features





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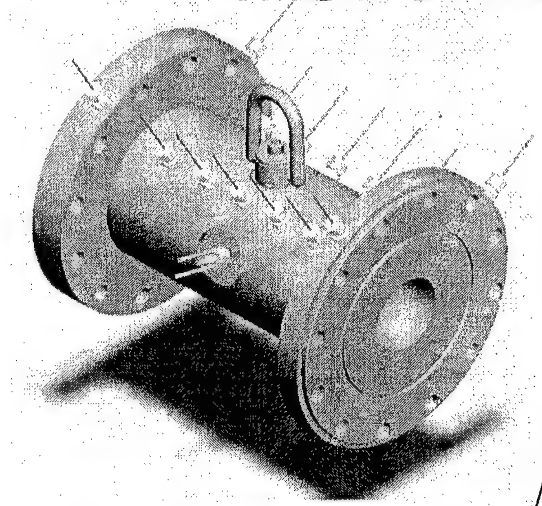
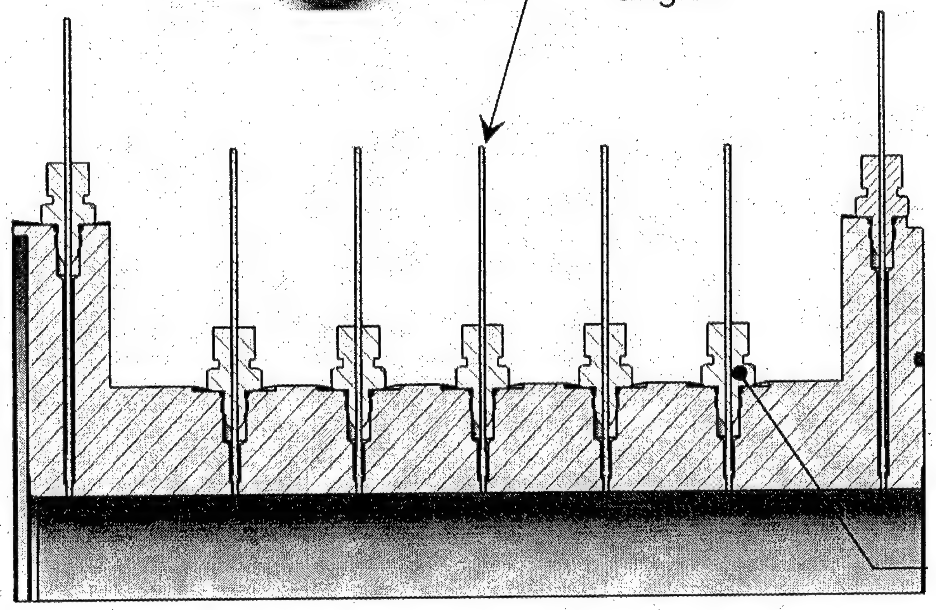
Instrumented Barrel Design Features

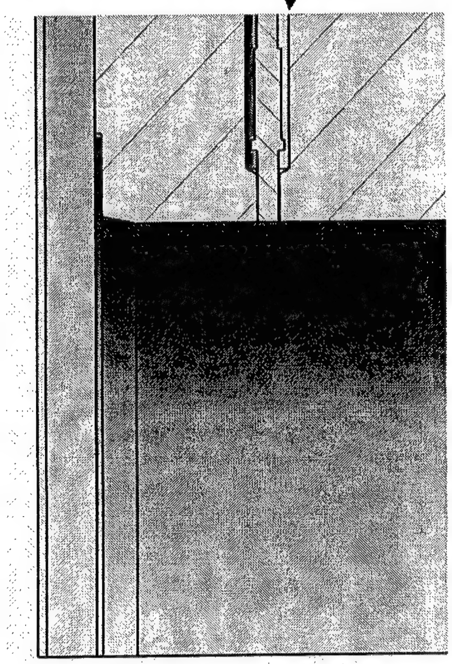


TC's at 7 axial planes along 2 circumferential angles



TC Port, seals on TC's outer covering (Stainless Steel, Viton O-Ring)

Allowance for accurate placement of thermocouple face



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Test Planning Overview

1. Testing Objectives
2. Phases of Test Program
3. Basic Approach for each Phase of Test Program

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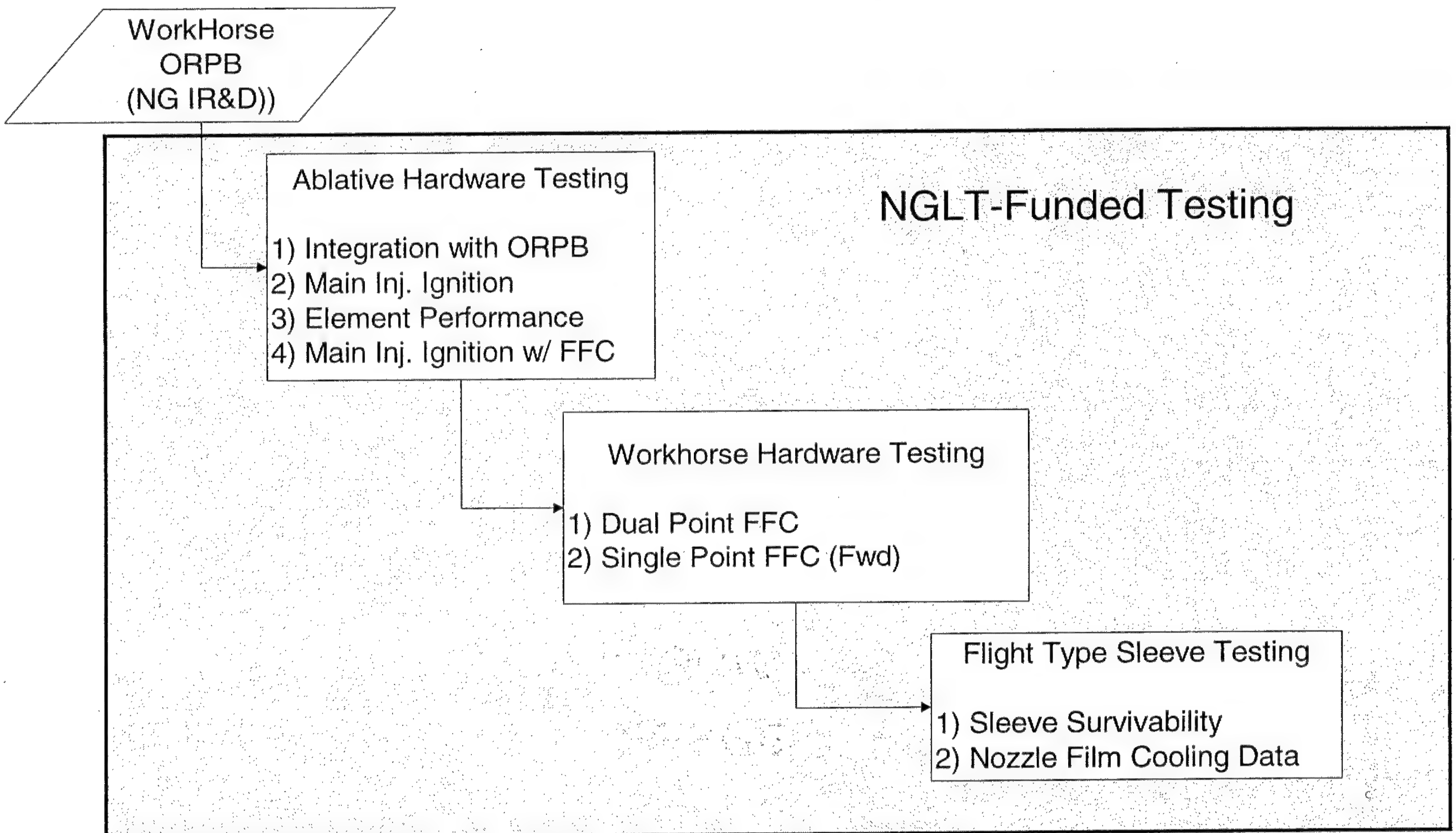
Three Phase Test Program Mitigates Risk, Obtains Needed Data



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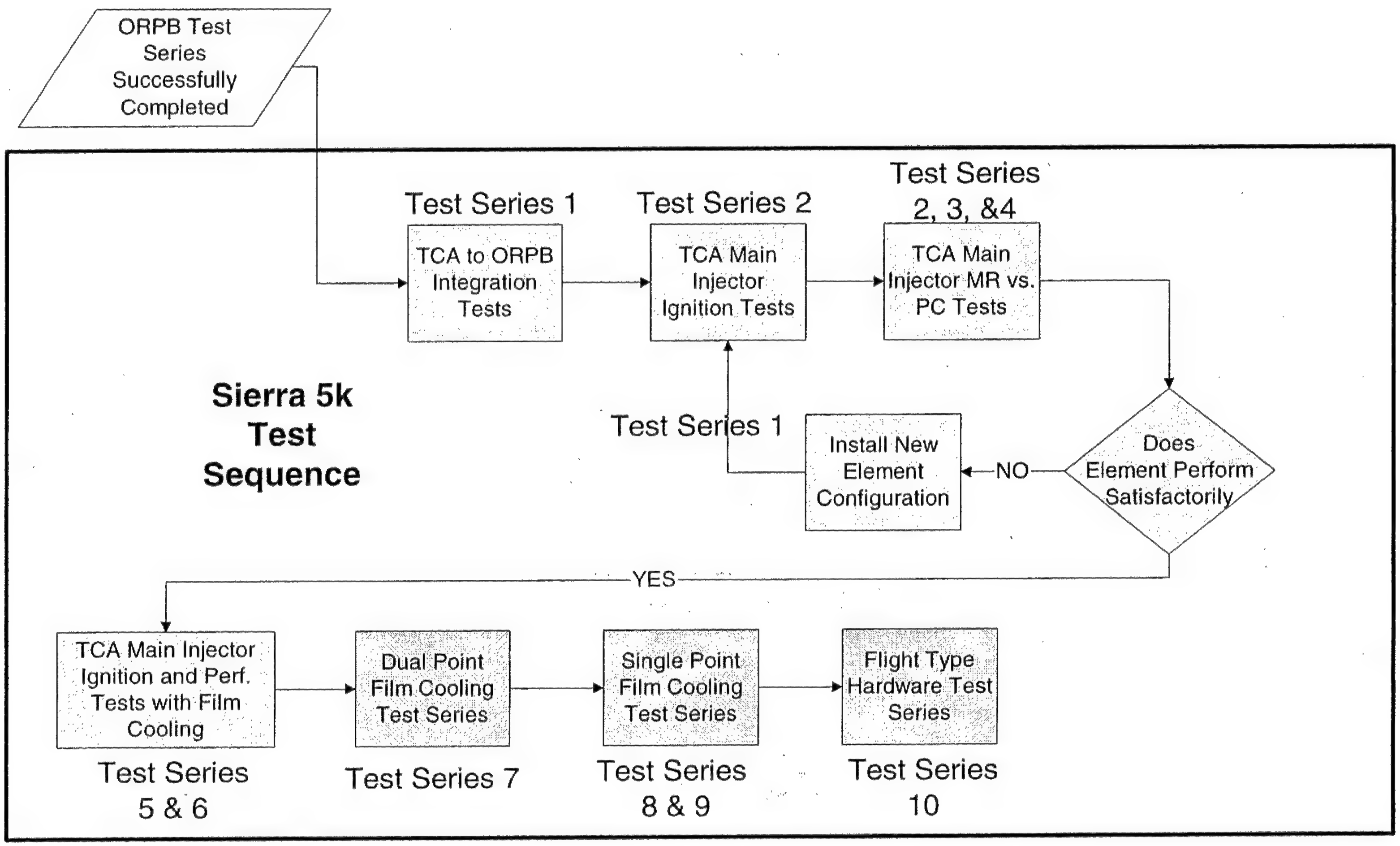
5k TCA Hot Fire Test Sequence



Yellow Box – Ablative Configurations
Green Box - Work Horse Configurations
Cyan Box - Flight Type Sleeve Configuration

Top Level Test Plan

Test Series	Objective	TCA Config.	TCA MR	Element MR	Chamber Pressure	Film Cooling Config	No. of Tests
1	• Integration / Checkout with ORPB	Ablative chamber w/o FFC	~60	~60	190 to 385	None	4
2	• Main Inj. Ignition • Chamber Wall Compatibility • Element Performance	Ablative chamber w/o FFC	3.147	3.147	740 To 1485	None	4
3	• Main Inj. Ignition • Chamber Wall Compatibility • Element Performance	Ablative chamber w/o FFC	2.7	2.7	740 To 1485	None	4
4	• Main Inj. Ignition • Chamber Wall Compatibility • Element Performance	Ablative chamber w/o FFC	3.2	3.2	740 To 1485	None	4
5	• Integration/Timing Fwd FFC • Chamber Wall Compatibility • Element Performance	Ablative chamber w/ FWD FFC	0.94 To 1.22	3.147	1760 To 1875	High FWD	3
6	• Integration/Timing Fwd FFC • Chamber Wall Compatibility • Element Performance	Ablative chamber w / FWD FFC	1.22 To 1.62	3.147	1750 To 1800	Low FWD	3
7	• Integration/Timing with both Fwd & Aft FFC • Chamber Wall Compatibility	Work Horse w / Fwd & Aft FFC	0.72 To 1.34	3.147	890 To 2045	Multiple Combinations	40
8	• Chamber Wall Compatibility	Fwd FFC only – Work Horse Hardware	0.94 to 1.22	3.147	1760 To 1875	High FWD	6
9	• Chamber Wall Compatibility	Fwd FFC only – Work Horse Hardware	1.22 To 1.62	3.147	1750 To 1800	Low FWD	6
10	• Integration with Flight Hardware • Chamber Wall Compatibility	Flight-Type Sleeve w/ Fwd FFC	~1.04	3.147	1835 & ~1100	High FWD	6

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Test Plan Details

- Detailed Hot Fire Test Plan & Instrumentation
  - Ablative Configurations
  - Work Horse Configurations
  - Flight Type Sleeve Configuration
- Data Reduction

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5k TCA Hot Fire Test Plan

To Date:

- The test plan has not been optimized / prioritized for the NGLT test duration (~6 wks testing, +2 wks setup).

Near-term Activity:

- Prioritize the test points using design-of-experiments
  - maximize data for model validation
  - work within the allocated resources

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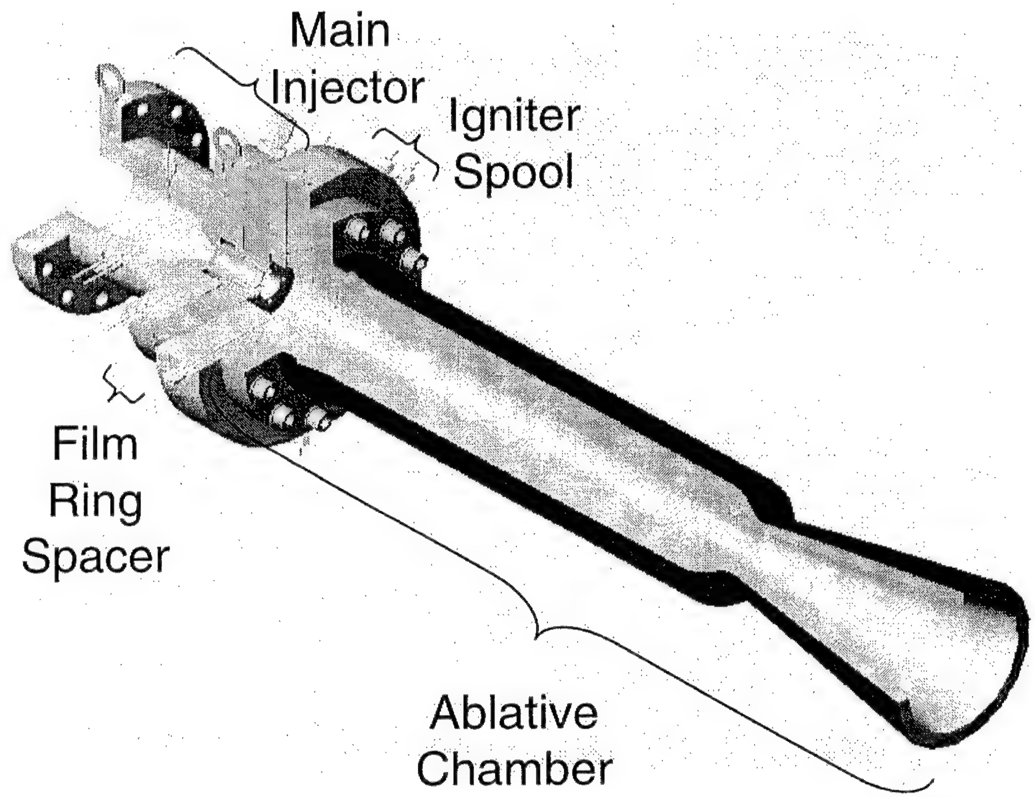
Test Series 1
ORPB Integration - Ablative Configuration

<u>Objectives:</u>

1. Demonstrate ability to run ORPB with TCA downstream
2. 4 tests

<u>Success Criteria:</u>

1. ORPB performance (Pc, T uniformity) not impacted by attachment of TCA
2. Igniter Spool temperature with acceptable limits



Test Series 2-4
Ablative Configuration
TCA Injector Ignition, Element Performance (No FFC)

Objectives:

1. Demonstrate ignition of TCA main injector without forward film cooling
2. Demonstrate TCA injector element performance (over Pc and MR box)
3. 12 tests

Success Criteria:

1. ORPB performance (Pc, T uniformity) not impacted by attachment of TCA
2. Ignition achieved with no adverse "popping"
3. Igniter Spool temperature with acceptable limits
4. Element performance within expected level

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Test Series 1 thru 4
Ablative Configuration Instrumentation

Provided instrumentation allows evaluation of:
- Ignition characteristics
- Element performance
- Face compatibility
- Igniter wall condition

Instrument Callout	Nomenclature	Clocking Looking Downstream	Axial Position from Injector Face	Sampling Rate	Red Line
TCA Main Injector GOX Supply					
GOX Supply Pressure	PGOXI	180		100 Hz	Yes
GOX Supply Temperature	TGOXI	0		20 Hz	
HiFreq Manifold Pressure	PGOXIHF	90		5k Hz	
TCA Fuel Supply System					
Fuel Supply Pressure	PFI			100 Hz	Yes
Fuel Supply Temperature	TFI			10 Hz	
Fuel Suppy Flowrate	WFI			20 Hz	
Main Injector Fuel System					
Main Fuel Venturi Inlet Pressure	PFVIMI			100 hz	Yes
Main Fuel Venturi Downstream Pressure	PFVDMI			50 hz	
Injector Manifold Fuel Pressure	PFJ	180		50 hz	
HiFreq Manifold Pressure	PFJHF	210		10k Hz	
Fuel Supply Temperature	TFJ	270		20 Hz	
Injector Face					
Injector Face Temperature	TINJ1	90	0	1k hz	Yes
Injector Face Temperature	TINJ2	330	0	1k hz	Yes
Chamber Conditions - Igniter section					
Steady State Pc (0-300 psia)	PCL	90	1.5	1k Hz	Yes
Steady State Pc (0-3000 psia) (same port as above)	PCH	90	1.5	1k Hz	Yes
Axial Accel	AAX			10 kHz	
Radial Accel	ARAD			10 kHz	
Wall Temperature (igniter spool)	TIGN1	60	0.5	50 Hz	
Wall Temperature (igniter spool)	TIGN3	60	1.5	50 Hz	
Wall Temperature (igniter spool)	TIGN4	180	1.5	50 Hz	Yes
Wall Temperature (igniter spool)	TIGN2	330	0.5	50 Hz	
Wall Temperature (igniter spool)	TIGN5	330	1.5	50 Hz	

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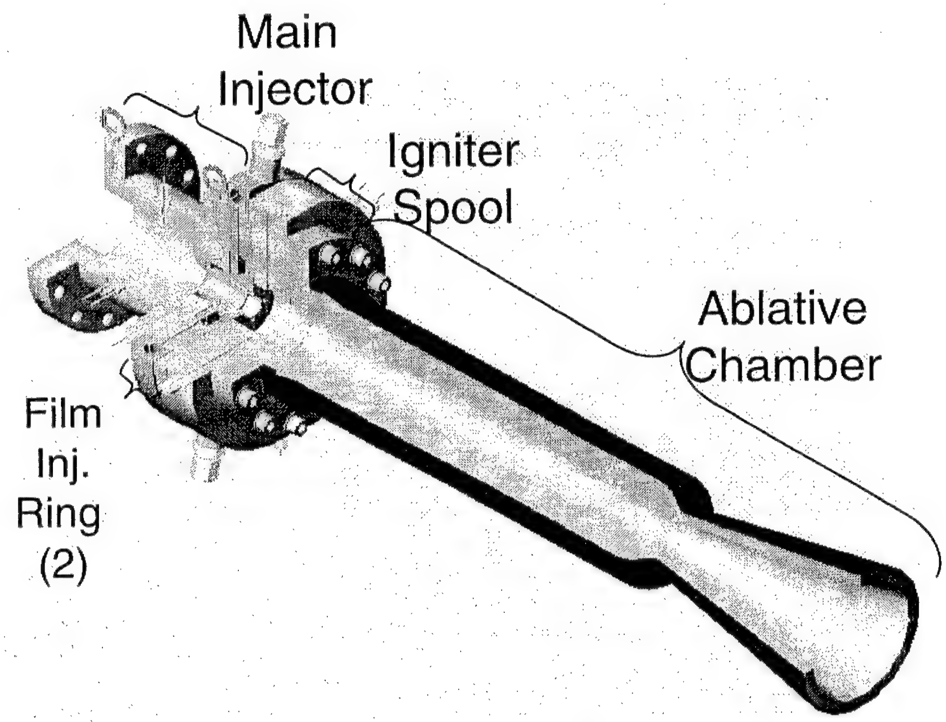
Test Series 5 & 6
Ablative Configuration
TCA Injector Ignition, Element Performance (w/ FFC)

Objectives:
1. Demonstrate ability to run ORPB with TCA downstream, with film cooling
2. Demonstrate ignition of TCA main injector, with film cooling
3. Demonstrate TCA performance with varying film cooling percentage
4. 6 tests

Success Criteria:
1. ORPB performance (Pc, T uniformity) not impacted by attachment of TCA
2. Ignition achieved with no adverse “popping”
3. Igniter Spool temperature with acceptable limits
4. Element performance within expected level



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Test Series 5 and 6
Ablative Configuration Instrumentation

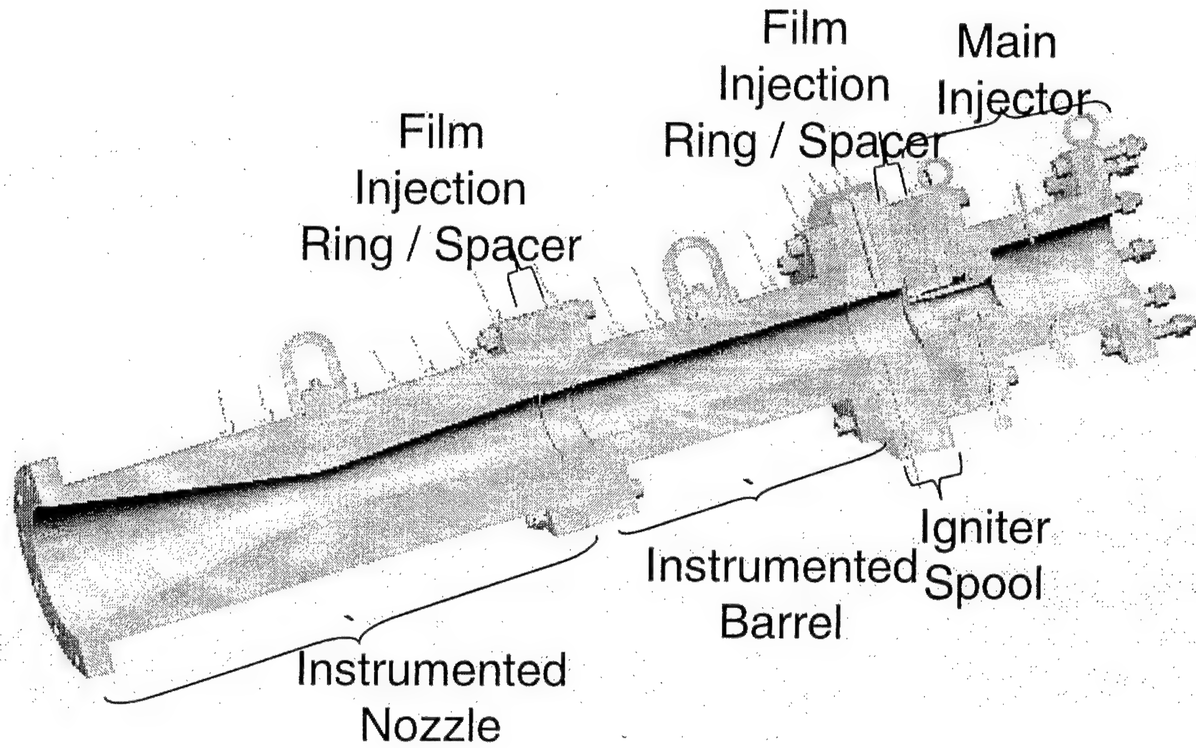
Instrumentation for Test Series 5 & 6 increased to allow measurement of forward film coolant operating conditions

Provided instrumentation allows evaluation of:

- Ignition characteristics
- Element performance
- Face compatibility
- Igniter wall condition

Instrument Callout	Nomenclature	Clocking Looking Downstream	Axial Position from Injector Face	Sampling Rate	Red Line
TCA Main Injector GOX Supply					
GOX Supply Pressure	PGOXI	180		100 Hz	Yes
GOX Supply Temperature	TGOXI	0		20 Hz	
HiFreq Manifold Pressure	PGOXIHF	90		5k Hz	
TCA Fuel Supply System					
Fuel Supply Pressure	PFI			100 Hz	Yes
Fuel Supply Temperature	TFI			10 Hz	
Fuel Suppy Flowrate	WFI			20 Hz	
Main Injector Fuel System					
Main Fuel Venturi Inlet Pressure	PFVIMI			100 hz	Yes
Main Fuel Venturi Downstream Pressure	PFVDMI			50 hz	
Injector Manifold Fuel Pressure	PFJ	180		50 hz	
HiFreq Manifold Pressure	PFJHF	210		10k Hz	
Fuel Supply Temperature	TFJ	270		20 Hz	
Injector Face					
Injector Face Temperature	TINJ1	90	0	1k hz	Yes
Injector Face Temperature	TINJ2	330	0	1k hz	Yes
Chamber Conditions - Igniter section					
Steady State Pc (0-300 psia)	PCL	90	1.5	1k Hz	Yes
Steady State Pc (0-3000 psia) (same port as above)	PCH	90	1.5	1k Hz	Yes
Axial Accel	AAX			10 kHz	
Radial Accel	ARAD			10 kHz	
Wall Temperature (igniter spool)	TIGN1	60	0.5	50 Hz	
Wall Temperature (igniter spool)	TIGN3	60	1.5	50 Hz	
Wall Temperature (igniter spool)	TIGN4	180	1.5	50 Hz	Yes
Wall Temperature (igniter spool)	TIGN2	330	0.5	50 Hz	
Wall Temperature (igniter spool)	TIGN5	330	1.5	50 Hz	
Forward Film Cooling Ring					
Fwd FFC Fuel Supply Temperature	TFFFCI			10 Hz	
Fwd FFC Fuel Venturi Inlet Pressure	PVIFFFC			10 Hz	Yes
Fwd FFC Fuel Venturi Downstream Pressure	PVDFFFC			10 Hz	
Fwd FFC Fuel Manifold Pressure	PMFFFC			10 Hz	

Test Series 7 & 8
Workhorse Configuration
Element Performance, Film Cooling Performance



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Test Series 7
Workhorse Configuration
Dual Point Film Cooling Testing

Objectives:

1. Demonstrate ability to run ORPB with TCA downstream and dual injection film cooling
2. Demonstrate TCA injector element performance with dual point film cooling
3. Collect film cooling performance data as a function of film and geometric parameters

Outline for Dual Point Film Cooling Study

- Independent forward and aft FFC flow fractions
- Cover range of equivalent film flows for 40K and 1M engines
- Nominal and 1/2 main injector flow
- 40 tests to fully characterize operating box

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Instrumentation for Test Series 7 Measures Element Performance, Wall Compatibility as Function of Film Cooling

Instrument Callout	Nomenclature	Clocking Looking Downstream	Axial Position from Injector Face	Sampling Rate	Red Line
TCA Main Injector GOX Supply					
GOX Supply Pressure	PGOXI	180		100 Hz	Yes
GOX Supply Temperature	TGOXI	0		20 Hz	
HiFreq Manifold Pressure	PGOXIHF	90		5k Hz	
TCA Fuel Supply System					
Fuel Supply Pressure	PFI			100 Hz	Yes
Fuel Supply Temperature	TFI			10 Hz	
Fuel Suppy Flowrate	WFI			20 Hz	
Main Injector Fuel System					
Main Fuel Venturi Inlet Pressure	PFVIMI			100 hz	Yes
Main Fuel Venturi Downstream Pressure	PFVDMI			50 hz	
Injector Manifold Fuel Pressure	PFJ	180		50 hz	
HiFreq Manifold Pressure	PFJHF	210		10k Hz	
Fuel Supply Temperature	TFJ	270		20 Hz	
Injector Face					
Injector Face Temperature	TINJ1	90	0	1k hz	Yes
Injector Face Temperature	TINJ2	330	0	1k hz	Yes
Chamber Conditions - Igniter section					
Steady State Pc (0-300 psia)	PCL	90	1.5	1k Hz	Yes
Steady State Pc (0-3000 psia) (same port as above)	PCH	90	1.5	1k Hz	Yes
Axial Accel	AAX			10 kHz	
Radial Accel	ARAD			10 kHz	
Wall Temperature (igniter spool)	TIGN1	60	0.5	50 Hz	
Wall Temperature (igniter spool)	TIGN3	60	1.5	50 Hz	
Wall Temperature (igniter spool)	TIGN4	180	1.5	50 Hz	Yes
Wall Temperature (igniter spool)	TIGN2	330	0.5	50 Hz	
Wall Temperature (igniter spool)	TIGN5	330	1.5	50 Hz	
Forward Film Cooling Ring					
Fwd FFC Fuel Supply Temperature	TFFFCI			10 Hz	
Fwd FFC Fuel Venturi Inlet Pressure	PVIFFFC			10 Hz	Yes
Fwd FFC Fuel Venturi Downstream Pressure	PVDFFFC			10 Hz	
Fwd FFC Fuel Manifold Pressure	PMFFFC			10 Hz	
Aft Film Cooling Ring					
Aft Film Fuel Supply Temperature	TAFFCI			10 Hz	
Aft film Fuel Venturi Inlet Pressure	PVIAFFC			10 Hz	Yes
Aft Film Fuel Venturi Downstream Pressure	PVDAFFC			10 Hz	
Aft FFC Fuel Manifold Pressure	PMAFFC			10 Hz	

Instrument Callout	Nomenclature	Clocking Looking Downstream	Axial Position from Injector Face	Sampling Rate	Red Line
Barrel Section - Heat Sink					
HiFreq PC	PCHF	75	8.925	10k Hz	Yes
Wall Temperature (Barrel Flange - upstream)	TBAR1	60	2.625	50 Hz	
Wall Temperature	TBAR3	60	4.625	50 Hz	
Wall Temperature	TBAR5	60	6.125	50 Hz	
Wall Temperature	TBAR7	60	7.625	50 Hz	
Wall Temperature	TBAR9	60	9.125	50 Hz	
Wall Temperature	TBAR11	60	10.625	50 Hz	
Wall Temperature (Barrel Flange - dwnstream)	TBAR13	60	12.526	50 Hz	Yes
Wall Temperature (Barrel Flange)	TBAR2	330	2.625	50 Hz	
Wall Temperature	TBAR4	330	4.625	50 Hz	
Wall Temperature	TBAR6	330	6.125	50 Hz	
Wall Temperature	TBAR8	330	7.625	50 Hz	
Wall Temperature	TBAR10	330	9.125	50 Hz	
Wall Temperature	TBAR12	330	10.625	50 Hz	
Wall Temperature (Barrel Flange - dwnstream)	TBAR14	330	12.526	50 Hz	Yes
Throat Section - Heat Sink					
Wall Temperature (Throat Flange - upstream)	TNOZ1	60	14.77	50 Hz	
Wall Temperature	TNOZ3	60	16.264	50 Hz	
Wall Temperature	TNOZ5	60	17.763	50 Hz	
Wall Temperature	TNOZ7	60	19.261	50 Hz	
Wall Temperature	TNOZ9	60	20.761	50 Hz	
Wall Temperature	TNOZ11	60	23	50 Hz	Yes
Wall Temperature	TNOZ13	60	24.747	50 Hz	
Wall Temperature	TNOZ15	60	26.247	50 Hz	
Wall Temperature (Throat Flange - upstream)	TNOZ2	330	14.77	50 Hz	
Wall Temperature	TNOZ4	330	16.264	50 Hz	
Wall Temperature	TNOZ6	330	17.763	50 Hz	
Wall Temperature	TNOZ8	330	19.261	50 Hz	
Wall Temperature	TNOZ10	330	20.761	50 Hz	
Wall Temperature	TNOZ12	330	23	50 Hz	Yes
Wall Temperature	TNOZ14	330	24.747	50 Hz	
Wall Temperature	TNOZ16	330	26.247	50 Hz	
Wall Static Pressure	PNOZ	345	19.261	1 kHz	

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Test Series 8 & 9 – Work Horse Configuration Single Point Film Cooling Testing Outline

- Thermal analysis indicates hardware will survive single point (forward injection only) film cooling tests
  - Without forward film coolant flow the front end hardware over heats
- Demonstrate forward film effectiveness at two chamber pressures
- 12 tests identified

Instrumentation for Test Series 8 & 9 Measures Element Performance, Wall Compatibility as Function of Film Cooling

Instrument Callout	Nomenclature	Clocking Looking Downstream	Axial Position from Injector Face	Sampling Rate	Red Line
TCA Main Injector GOX Supply					
GOX Supply Pressure	PGOXI	180		100 Hz	Yes
GOX Supply Temperature	TGOXI	0		20 Hz	
HiFreq Manifold Pressure	PGOXIHF	90		5k Hz	
TCA Fuel Supply System					
Fuel Supply Pressure	PFI			100 Hz	Yes
Fuel Supply Temperature	TFI			10 Hz	
Fuel Suppy Flowrate	WFI			20 Hz	
Main Injector Fuel System					
Main Fuel Venturi Inlet Pressure	PFVIMI			100 hz	Yes
Main Fuel Venturi Downstream Pressure	PFVDMI			50 hz	
Injector Manifold Fuel Pressure	PFJ	180		50 hz	
HiFreq Manifold Pressure	PFJHF	210		10k Hz	
Fuel Supply Temperature	TFJ	270		20 Hz	
Injector Face					
Injector Face Temperature	TINJ1	90	0	1k hz	Yes
Injector Face Temperature	TINJ2	330	0	1k hz	Yes
Chamber Conditions - Igniter section					
Steady State Pc (0-300 psia)	PCL	90	1.5	1k Hz	Yes
Steady State Pc (0-3000 psia) (same port as above)	PCH	90	1.5	1k Hz	Yes
Axial Accel	AAX			10 kHz	
Radial Accel	ARAD			10 kHz	
Wall Temperature (igniter spool)	TIGN1	60	0.5	50 Hz	
Wall Temperature (igniter spool)	TIGN3	60	1.5	50 Hz	
Wall Temperature (igniter spool)	TIGN4	180	1.5	50 Hz	Yes
Wall Temperature (igniter spool)	TIGN2	330	0.5	50 Hz	
Wall Temperature (igniter spool)	TIGN5	330	1.5	50 Hz	
Forward Film Cooling Ring					
Fwd FFC Fuel Supply Temperature	TFFFCI			10 Hz	
Fwd FFC Fuel Venturi Inlet Pressure	PVIFFFC			10 Hz	Yes
Fwd FFC Fuel Venturi Downstream Pressure	PVDFFFC			10 Hz	
Fwd FFC Fuel Manifold Pressure	PMFFFC			10 Hz	

Instrument Callout	Nomenclature	Clocking Looking Downstream	Axial Position from Injector Face	Sampling Rate	Red Line
Barrel Section - Heat Sink					
HiFreq PC	PCHF	75	8.925	10k Hz	Yes
Wall Temperature (Barrel Flange - upstream)	TBAR1	60	2.625	50 Hz	
Wall Temperature	TBAR3	60	4.625	50 Hz	
Wall Temperature	TBAR5	60	6.125	50 Hz	
Wall Temperature	TBAR7	60	7.625	50 Hz	
Wall Temperature	TBAR9	60	9.125	50 Hz	
Wall Temperature	TBAR11	60	10.625	50 Hz	
Wall Temperature (Barrel Flange - dwnstream)	TBAR13	60	12.526	50 Hz	Yes
Wall Temperature (Barrel Flange)	TBAR2	330	2.625	50 Hz	
Wall Temperature	TBAR4	330	4.625	50 Hz	
Wall Temperature	TBAR6	330	6.125	50 Hz	
Wall Temperature	TBAR8	330	7.625	50 Hz	
Wall Temperature	TBAR10	330	9.125	50 Hz	
Wall Temperature	TBAR12	330	10.625	50 Hz	
Wall Temperature (Barrel Flange - dwnstream)	TBAR14	330	12.526	50 Hz	Yes
Throat Section - Heat Sink					
Wall Temperature (Throat Flange - upstream)	TNOZ1	60	14.77	50 Hz	
Wall Temperature	TNOZ3	60	16.264	50 Hz	
Wall Temperature	TNOZ5	60	17.763	50 Hz	
Wall Temperature	TNOZ7	60	19.261	50 Hz	
Wall Temperature	TNOZ9	60	20.761	50 Hz	
Wall Temperature	TNOZ11	60	23	50 Hz	Yes
Wall Temperature	TNOZ13	60	24.747	50 Hz	
Wall Temperature	TNOZ15	60	26.247	50 Hz	
Wall Temperature (Throat Flange - upstream)	TNOZ2	330	14.77	50 Hz	
Wall Temperature	TNOZ4	330	16.264	50 Hz	
Wall Temperature	TNOZ6	330	17.763	50 Hz	
Wall Temperature	TNOZ8	330	19.261	50 Hz	
Wall Temperature	TNOZ10	330	20.761	50 Hz	
Wall Temperature	TNOZ12	330	23	50 Hz	Yes
Wall Temperature	TNOZ14	330	24.747	50 Hz	
Wall Temperature	TNOZ16	330	26.247	50 Hz	
Wall Static Pressure	PNOZ	345	19.261	1 kHz	

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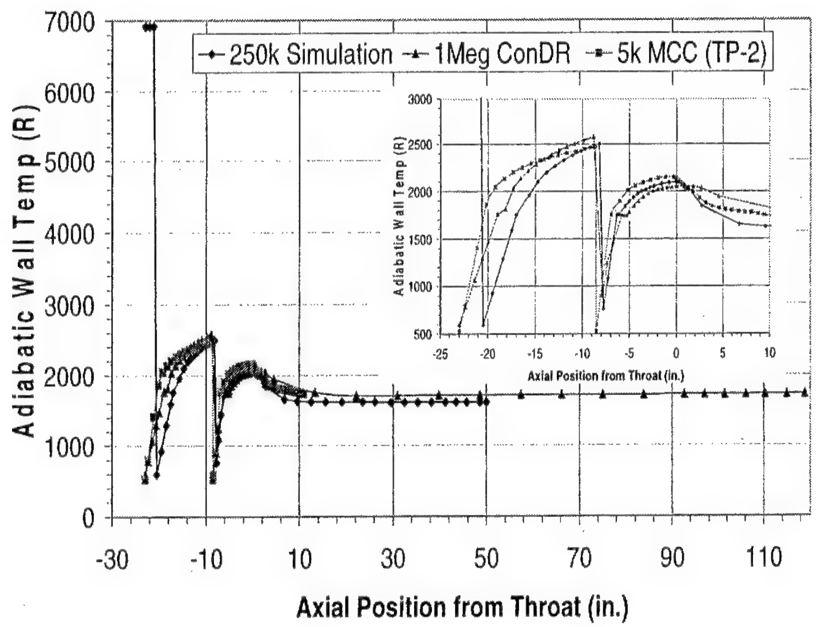
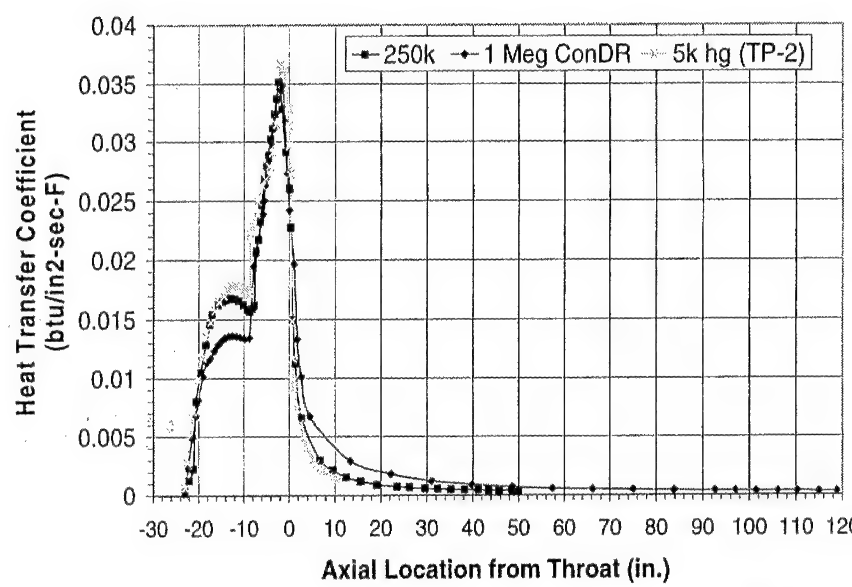
Flight Type Sleeve Tests Planned to Simulate TR107 Thermal Boundary Conditions

- Demonstrate operation at nominal and 1/2 PC
- Twos series of 3 tests - increasing duration





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Instrumentation for Test Series 10 Measures Element Performance, Wall Compatibility as Function of Film Cooling

Instrument Callout	Nomenclature	Clocking Looking Downstream	Axial Position from Injector Face	Sampling Rate	Red Line
TCA Main Injector GOX Supply					
GOX Supply Pressure	PGOXI	180		100 Hz	Yes
GOX Supply Temperature	TGOXI	0		20 Hz	
HiFreq Manifold Pressure	PGOXIHF	90		5k Hz	
TCA Fuel Supply System					
Fuel Supply Pressure	PFI			100 Hz	Yes
Fuel Supply Temperature	TFI			10 Hz	
Fuel Suppy Flowrate	WFI			20 Hz	
Main Injector Fuel System					
Main Fuel Venturi Inlet Pressure	PFVIMI			100 hz	Yes
Main Fuel Venturi Downstream Pressure	PFVDMI			50 hz	
Injector Manifold Fuel Pressure	PFJ	180		50 hz	
HiFreq Manifold Pressure	PFJHF	210		10k Hz	
Fuel Supply Temperature	TFJ	270		20 Hz	
Injector Face					
Injector Face Temperature	TINJ1	90	0	1k hz	Yes
Injector Face Temperature	TINJ2	330	0	1k hz	Yes
Chamber Conditions - Igniter section					
Steady State Pc (0-300 psia)	PCL	90	1.5	1k Hz	Yes
Steady State Pc (0-3000 psia) (same port as above)	PCH	90	1.5	1k Hz	Yes
Axial Accel	AAX			10 kHz	
Radial Accel	ARAD			10 kHz	
Wall Temperature (igniter spool)	TIGN1	60	0.5	50 Hz	
Wall Temperature (igniter spool)	TIGN3	60	1.5	50 Hz	
Wall Temperature (igniter spool)	TIGN4	180	1.5	50 Hz	Yes
Wall Temperature (igniter spool)	TIGN2	330	0.5	50 Hz	
Wall Temperature (igniter spool)	TIGN5	330	1.5	50 Hz	
Forward Film Cooling Ring					
Fwd FFC Fuel Supply Temperature	TFFFCI			10 Hz	
Fwd FFC Fuel Venturi Inlet Pressure	PVIFFFC			10 Hz	Yes
Fwd FFC Fuel Venturi Downstream Pressure	PVDFFFC			10 Hz	
Fwd FFC Fuel Manifold Pressure	PMFFFC			10 Hz	
Flight Dump Sleeve					
Dump Sleeve Fuel Supply Temperature	TDSI			10 Hz	
Dump Sleeve Fuel Venturi Inlet Pressure	PVIDS			10 Hz	Yes
Dump Sleeve Fuel Venturi Downstream Pressure	PVDDS			10 Hz	
Dump Sleeve FFC Fuel Manifold Pressure	PMDS			10 Hz	

Instrument Callout	Nomenclature	Clocking Looking Downstream	Axial Position from Injector Face	Sampling Rate	Red Line
Throat Section - Heat Sink					
Wall Temperature (Throat Flange - upstream)	TNOZ1	60	14.77	50 Hz	
Wall Temperature	TNOZ3	60	16.264	50 Hz	
Wall Temperature	TNOZ5	60	17.763	50 Hz	
Wall Temperature	TNOZ7	60	19.261	50 Hz	
Wall Temperature	TNOZ9	60	20.761	50 Hz	
Wall Temperature	TNOZ11	60	23	50 Hz	Yes
Wall Temperature	TNOZ13	60	24.747	50 Hz	
Wall Temperature	TNOZ15	60	26.247	50 Hz	
Wall Temperature (Throat Flange - upstream)	TNOZ2	330	14.77	50 Hz	
Wall Temperature	TNOZ4	330	16.264	50 Hz	
Wall Temperature	TNOZ6	330	17.763	50 Hz	
Wall Temperature	TNOZ8	330	19.261	50 Hz	
Wall Temperature	TNOZ10	330	20.761	50 Hz	
Wall Temperature	TNOZ12	330	23	50 Hz	Yes
Wall Temperature	TNOZ14	330	24.747	50 Hz	
Wall Temperature	TNOZ16	330	26.247	50 Hz	
Wall Static Pressure	PNOZ	345	19.261	1 kHz	

Throat section measurements allow direct comparison to previous work horse test results.

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Data Reduction Approach

Testing objectives for film cooling:

- Determine the local (axially varying) recovery temperature and heat transfer coefficient. These data will be used to:
  - Discern the fluid "latent heating & cracking" length
    - Forward
    - Aft
  - Discern the single point film cooling effectiveness
    - Forward
  - Discern the two point film cooling effectiveness
    - Superposition principal

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TCA Hot Wall Instrumentation Utilizes Dual Junction Coaxial Thermocouples

- Rugged
- Fast response
- Matched to wall material and response
- Simple to use (no water cooling circuits)
- Relatively inexpensive
- Successfully demonstrated numerous times for measurement of local wall heat fluxes
  - Kidd, C.T., "Coaxial Surface Thermocouples – Analytical & Experimental Considerations for Aerothermal Heat Flux Measurement Applications", ISA, 1990, Paper 90-126
  - Hollis,B.R.,"Users Manual for the One-Dimensional Hypersonic Aero-thermodynamic (1DHEAT) Data Reduction Code", NASA CR-4691
  - Hedlund, E.R., et.al. "Heat Transfer Testing in the NSWC Hypervelocity Wind Tunnel Utilizing Co-axial Surface Thermocouples", NSWC MP80-151, March 19, 1080
  - Philippart, K.D."Diagnostic Developments for Velocity & Temperature Measurements in Uni-Element Rocket Environments", AFIT/CI/CIA 95-72, Aug 1995
  - Schieb, D.J. "Effects of Liquid Transpiration Cooling on Heat Transfer to the Diverging Region of a Porus-Walled Nozzle", AIIF/GA/ENY/97D-04, Dec, 1997
  - Cahoon, N.T. "Heating Parameter Estimation Using Coaxial Thermocouple Gages in Wind Tunnel Test Articles", AFIT/GAE/AA/84D-3, Dec. 1984

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TCA Hot Wall Instrumentation Utilizes Co-axial Thermocouples

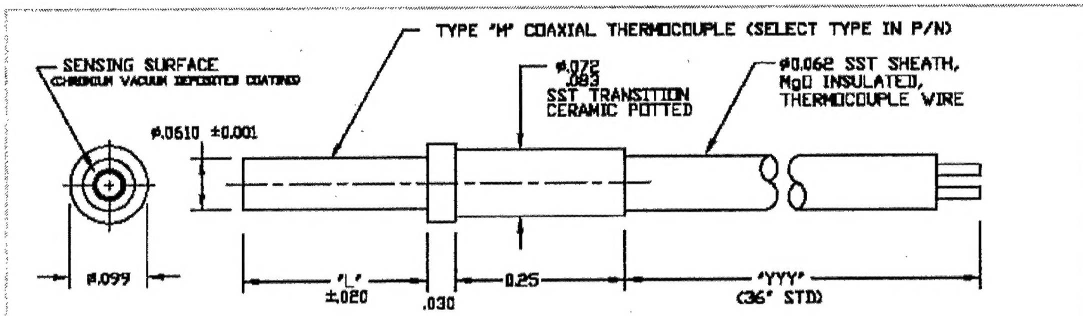
- Planned sampling rate is 50 Hz. Each thermocouple will provide a "hot wall" and in-depth transient thermal response to the applied heat load.

Injector Face TC's

- Iron/nickel type closely matches the thermal characteristics of the brass

Igniter/barrel/nozzle TC's

- Type E closely matches the thermal characteristics of the Inconel 625



NOTES:

1. The TCS-061-"M"-"L"-"YYY"-11354 is a coaxial surface thermocouple which will provide microsecond response time metal wall surface temperature measurements when properly installed flush in metal wall surface. In many cases the surface temperature history may be used to compute fast response heat transfer rates. An included backside thermocouple may be used for steady state heat transfer rate computations.
2. The coaxial surface thermocouple may be press fit, slip fit, soldered, or cemented into place. Press fit tool must press against the ø.099 diameter thermocouple and avoid placing stress on the ø.088 diameter transition area at the rear.
3. Other diameters and configurations are available with the SST sheathed high temperature leadwire.
4. The standard lead wire construction is stainless steel sheathed MgO insulated thermocouple cable. If desired, the user may add flexible cable extension after installation or it can be added at MEDTHERM.
5. Replace "M" in the P/N by the ISA thermocouple material code letter for the desired thermocouple material, (E for chromel/constantan, J for iron/constantan, T for copper/constantan, K for chromel/alumel).
6. Replace "L" in P/N by probe length in inches, 0.200" standard.
7. If other than 36 inches standard length desired, replace "YYY" in P/N by leadwire length in inches.

TCS-061-"M"-"L"-CR-"YYY"-11354
COAXIAL SURFACE THERMOCOUPLE

MEDTHERM CORPORATION

1/23/87
9/22/01
GMG

A 11354

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Summary

- Hardware design enables incremental study of film cooling and injector performance characteristics
  - Component and assembly designs have been established for all necessary test hardware
  - Instrumentation specified
- Preliminary test plan has been proposed
  - Test plan needs to be prioritized for NGLT funding
- A data reduction approach for the film cooling data has been developed
- Data supports validation of both analytical and CFD models

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